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## Dynamic calculation of knife refining machines together with a supporting structure

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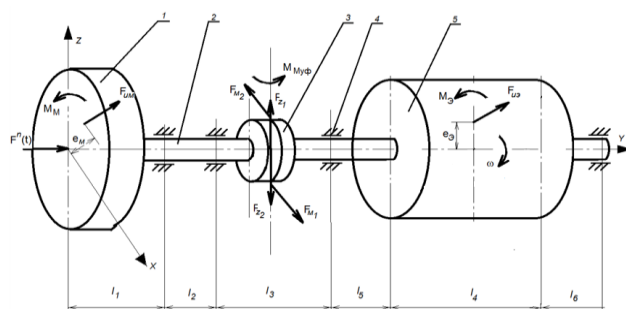
**Abstract.** The research subject is the method of dynamic calculation of knife refining machines together with the supporting structure. The design of refiners and supporting structures is carried out by various organizations. The knife refining machine and the supporting structure are a single dynamic system and, therefore, they must be calculated together. The forces exciting the oscillations of the refiners are investigated. Dynamic and mathematical models of the system are developed. The proposed method of dynamic calculation has been successfully tested on TF-52 and TWIN-66 refiners by OJSC “Solikamskbumprom”. The developed method of dynamic calculation can be used in other industries, such as metallurgical and mining.

## 1. Introduction

Knife refining machines are machines with high dynamics [1, 2]. They are installed on a separate foundation or on the floor with or without vibration insulators. As a rule, support structures and these machines are designed by various organizations. The refiner and the supporting structure are a single system and, therefore, they must be dynamically calculated together. The article develops a methodology for such a dynamic calculation.

## 2. Forces causing oscillations

The main node that causes the oscillations of the refiners is the rotor [3]. The rotor diagram is shown in figure 1.



**Figure 1.** Diagram of the refiner rotor and forces acting on it: 1- disk; 2- shaft; 3- coupling; 4- bearing supports; 5- electric motor rotor.

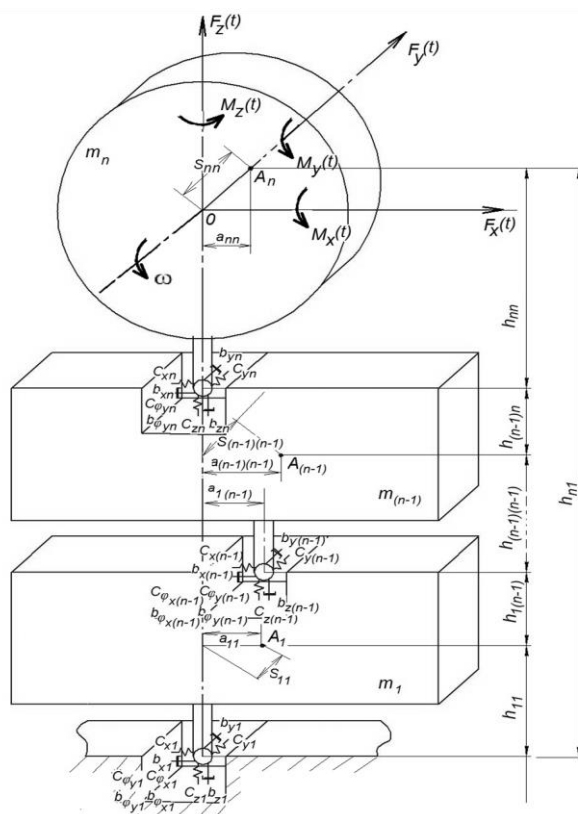
Forces and moments of forces acting in the system are as follows: inertial forces of unbalanced masses of the rotor of the refiner and the engine [4]; torque caused by the momentary imbalance of the rotor of the refiner [1]; mechanical and hydrodynamic effects of the refined material [5, 6, 7]; forces and moments of forces caused by misalignment of the rotors of the refiner and the engine [8].

All these forces and moments rotate with the same frequency  $\omega$ . Phases and amplitudes of forces may change over time (for example, when the plate is worn or temperature changes in the refining zone). In all cases, the simple summation of the amplitudes of all harmonic loads based on the principle of superposition leads to a significant and unjustified overestimation of the calculated parameters of the oscillations of the refiners and their supporting structures. Therefore, probabilistic methods are used in dynamic calculations.

According to the Lyapunov theorem, the law of distribution of the sum of random numbers with the same distribution with an unlimited increase in the number of terms approaches the normal one [9]. Therefore, the exciting oscillations of forces and moments of forces are determined according to this law of the distribution according to the known dependencies.

### 3. Dynamic and mathematical models

To build a dynamic system, the method of partitioning a complex dynamic system into partial subsystems is adopted [10, 11]. The system is divided into  $n$ -mass subsystems: a rigid machine, a rigid foundation, a rigid intercommunication overlap, etc. The dynamic model of the system is shown in figure 2.



**Figure 2.** Dynamic model of a refining machine together with supporting structure.

Under dynamic effects, the system performs spatial oscillations, which are determined by the coordinate values: displacements  $x_i$ ,  $y_i$ ,  $z_i$ , centres of mass and rotation angles  $\varphi_i$  of the foundation ( $x_1$ ,  $y_1$ ,  $z_1$ ,  $\varphi_{x1}$ ,  $\varphi_{y1}$ ), ... ( $n-1$ ), of the machine part ( $x_{n-1}$ ,  $y_{n-1}$ ,  $z_{n-1}$ ,  $\varphi_{xn-1}$ ,  $\varphi_{yn-1}$ ), the rotor of the refiner ( $x_n$ ,  $y_n$ ,  $z_n$ ,  $\varphi_{yn}$ ). The study of oscillations is conducted in a linear formulation.

Based on the d'Alembert principle, a system of interrelated differential equations is obtained, describing the oscillations of the system:

$$\begin{aligned}
 & m_n \ddot{u}_n + m_{n-1} \ddot{u}_{n-1} + \dots + m_1 \ddot{u}_1 + b_{u_n}(\dot{u}_n - \dot{u}_{n-1} - \dots - \dot{u}_1 - h_{nn}\dot{\varphi}_{u_n} - \\
 & - h_{(n-1)(n-1)}\dot{\varphi}_{u_{n-1}} - \dots - h_{11}\dot{\varphi}_{u_1}) + C_{u_n}(u_n - u_{n-1} - \dots - u_1 - h_{nn}\varphi_{u_n} - \\
 & - h_{(n-1)(n-1)}\varphi_{u_{n-1}} - \dots - h_{11}\varphi_{u_1}) = F_u(t) \\
 & \theta_{u_n} \ddot{\varphi}_{u_n} + \theta_{u_{n-1}} \ddot{\varphi}_{u_{n-1}} + \dots + \theta_{u_1} \ddot{\varphi}_{u_1} + m_n \ddot{x}_n h_{nn} + m_{n-1} \ddot{x}_{n-1} h_{(n-1)(n-1)} + \dots + \\
 & m_1 \ddot{x}_1 h_{11} - m_n \ddot{z}_n a_{nn} - m_{n-1} \ddot{z}_{n-1} a_{(n-1)(n-1)} - \dots - m_1 \ddot{z}_1 a_{11} - m_n \ddot{y}_n s_{nn} + \\
 & m_{n-1} \ddot{y}_{n-1} s_{(n-1)(n-1)} + \dots + m_1 \ddot{y}_1 s_{11} + b_{\varphi_{un}}(\dot{\varphi}_{u_n} - \dot{\varphi}_{u_{n-1}}) + C_{\varphi_{un}}(\varphi_{u_n} - \varphi_{u_{n-1}}) = M_u(t),
 \end{aligned}$$

where  $n = 1, 2, \dots, n$ ;  $u = x, y, z$ ;  $z_1 \dots z_{n-1}, z_n$ ;  $x_1 \dots x_{n-1}, x_n$ ;  $y_1 \dots y_{n-1}, y_n$  – movement of the mass centres of the corresponding elements of the refiner in the directions  $x, y, z$ ;  $\varphi_{u_1} \dots \varphi_{u_{n-1}}, \varphi_{u_n}$  – angles of rotation relative to the centres of rigidity of the masses of the corresponding elements;  $\omega$  – rotor speed;  $\theta_{u_1} \dots \theta_{u_{n-1}}, \theta_{u_n}$  – mass moments of inertia of elements of a multi-mass system about axes passing through the centres of their masses;  $m_n, A_n$  – mass and mass centres respectively;  $C_{u_n}, C_{\varphi_{un}}$  – stiffness coefficients of supporting structures, respectively, for vertical, horizontal, axial and rotary movements;  $b_{u_n}, b_{\varphi_{un}}$  – the coefficients of the inelastic resistance of the support structures, respectively, with vertical, horizontal, axial and rotational movements;  $s_{nn}, h_{nn}, a_{nn}$  – the distance between the centres of the  $n$ -th mass and the rigidity of the support element;  $F_u(t), M_u(t)$  – total forces and moments of forces exciting oscillations of the system.

The own frequencies and waveforms of a system are determined from a system of homogeneous differential equations obtained without taking into account inelastic resistances in the system. A particular solution of the system of equations is sought in the form  $v_k = S_{avk}^{(1)} \sin \omega t + S_{avk}^{(2)} \cos \omega t$ , where:  $\omega_0$  is the lowest frequency of free oscillations. Substituting this solution into the resulting differential equations, we obtain a homogeneous system of algebraic equations. The frequency of free oscillations of the system can be found from the equality to zero of the main determinant of this system.

Forced oscillations of the system are investigated by privately solving the system of differential equations in the form  $v_k = S_{avk}^{(1)} \sin \omega t + S_{avk}^{(2)} \cos \omega t$ , where  $v=y, z, x, \varphi_x, \varphi_y, \varphi_z$ ;  $k = 1, 2, \dots, n-1, n$ . Solving the system of equations for  $S_{avk}^{(1)}$  и  $S_{avk}^{(2)}$ , allows us to determine the amplitudes of the vibratory displacements of the masses of the system  $S_{avk} = [(S_{avk}^{(1)})^2 + (S_{avk}^{(2)})^2]^{1/2}$ .

#### 4. Testing methods of dynamic calculation

Based on the mathematical model, a method for dynamic calculation of knife refining machines together with the supporting structure has been developed. A computer program using the mathematical software complex “Maple 15” has been developed according to the methodology.

The TF-52 and TWIN-66 refiners of OJSC “Solikamskbumprom” were calculated, the first refiner being installed on the intermediate floor, and the second on a separate foundation. The resulting lower frequencies of free oscillations are presented in table 1. The error in determining the frequency does not exceed 8%.

**Table 1.** The lowest frequency of free oscillations of the refiners together with the supporting structure.

Refiner brand	Frequency, $\omega_0$ , rad/s		Error, %
	Theory	Experiment	
TWIN-66	47.6	50.8	6.3
TF-52	43.2	46.9	7.9

Next, the calculated values of the amplitudes of oscillations of the system elements are compared with the regulatory unbalance of the refiner rotor with the permissible vibration parameters regulated by GOST 26493-85 and GOST 12.1.012-2004 [12,13]. If the calculated values exceed the allowable values, it is necessary to develop methods and means of vibration protection.

## 5. Conclusion

The design of knife refining machines and their supporting structures is carried out by various organizations, although they represent a single dynamic system. The method of dynamic calculation of this unified system has been developed and tested positively. The proposed method of dynamic calculation can be used in other industries, such as metallurgical and mining.

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